Life Cycle Assessment of Point-of-Lay Birds to Frozen Chicken Production in Southwestern Nigeria

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1. Introduction

Poultry production is one of the major contributors to global environmental degradation. Currently, livestock raised for meat uses about a third of global ice-free terrestrial land and produces 18% of global greenhouse gas (GHG) emissions. This is more than the global transportation sector (FAO, 2006). Livestock production is also one of the main drivers of deforestation and degradation of wildlife habitats. Due to increasing population size and per capita meat consumption in the developing world, consumption of global meat is expected to double between 1999 and 2050 (FAO, 2006). Such increases will also double the impacts of frozen chicken on the environment unless more efficient chicken production methods are adopted.

Policy makers are increasingly using environmental variables in decision-making and one of the ways to generate environmental information involves Life Cycle Assessment (LCA) methodology that measures the environmental impacts of a product throughout its life cycle (de Alvarenga et al., 2011). LCA is a method for integral assessment of the environmental impacts of products, processes or services by including all phases of the life cycle by quantifying and evaluating the resources consumed. It is a methodology for examining environmental impacts associated with a product, process or service ''from cradle to grave'', that is from production of the raw materials to ultimate disposal of wastes (Lundie and Peters, 2005) such as land or fossil fuels, and the emissions to the environment, such as ammonia or methane. Feed production according to Boggia et al., (2010) and Hanh et al. (2011) has been identified as one of the major contributors to the environmental impacts (50-85% for climate change, 64-97% for eutrophication potential, 70-96% for energy use) of animal production systems.

Furthermore, LCA is used to report on and analyze energy and water resource issues across the life cycle of agricultural products. It is considered to be a tool that can be applied to evaluate agricultural production systems and it is based on an inventory of the resources consumed and the emissions to the environment at each stage of the product life cycle. Human health, natural resources and natural environment are classified as areas of protection in life cycle impact assessment (LCIA) by International Standards Organization (ISO 14044, 2006).

Environmental impacts can be classified in many ways which relate to the scale of the impacts, the timing of the impacts, and the phase of production and the target of the impact (Koskela, 2011). The impacts on the environmental can be local, regional or global; can be past, current and future (Seiffert, 2008). Previous operations may lead to groundwater pollution in the distant future (Koskela, 2011). For Japanese beef cow-calf system, Ogino et al. (2007) evaluated the environmental impacts contributed by the identified activities, and discussed approaches to lower them.

In agricultural production and processing systems, greenhouse gases (GHGs) such as CO_2, CH_4, in addition to N_2O can be emitted from fossil fuel-related operations. Biswas et al. (2008) opined that a holistic approach is needed if overall impact of the agricultural production systems on global greenhouse emissions is to be addressed. This has the advantage of identifying environmental impacts of all stages in the production cycle rather than focusing on a single source of GHG emission for comparative or improvement purposes (Biswas et al., 2008); which is the primary purpose of this studies. This study considered frozen chicken processes ranging from feed production, animal management, slaughtering, defeathering, scalding, packaging to freezing (Fig. 1).

Hence, the objectives of this study are: (i) to estimate the potential environmental impacts of large-scale poultry layer system from point-of-lay to frozen chicken; (ii) to investigate the effects of four scenarios in processes from point-of-lay to frozen chicken.

2. Materials and methods

LCA methodology consists of four major stages: (i) Goal and scope definition, (ii) Life cycle inventory, (iii) Life cycle impact assessment, and (iv) Interpretation of result. The functional unit (FU), towards which all the impacts are allocated, is defined as 1.35 kg of marketed frozen chicken. The system boundary, indicated by the dashed line in Figure 1, covers the major processing activities from point-of-lay to frozen chicken production.

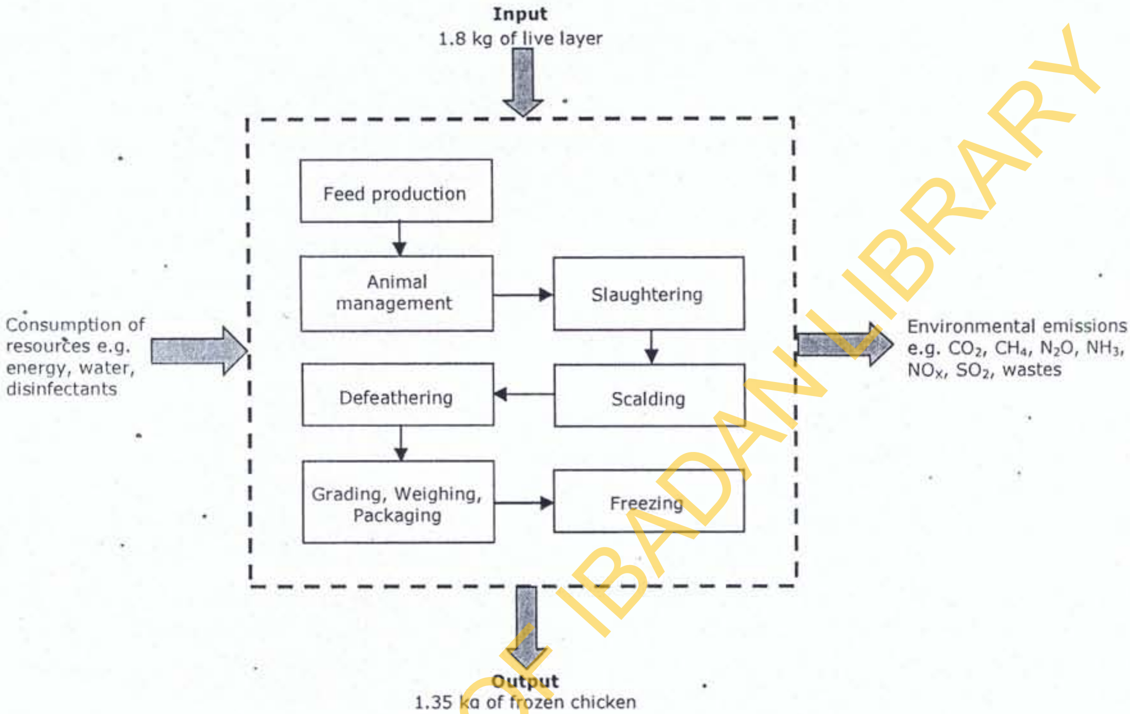

Figure 1: System boundary of frozen chicken production in LCA study

Table 1: Description of scenarios

Scenario	Power source		Other important features of scenario
	Purchased electricity	Diesel generators	
Scenario 1	100%	0%	Purchased electricity is based on 22.4% hydropower and 77.6% thermal power
Scenario 2	0%	100%	Electricity from diesel stand-by generators
Scenario 3	50%	50%	Purchased electricity is based on 22.4% hydropower and 77.6% thermal power
Scenario 4	50%	50%	Similar to scenario 3 except that purchased electricity generation is based on 50% hydropower and 50% thermal power

In this study, four scenarios were examined for assessing environmental impacts as presented in Table 1. Power mix in the national grid, based on the installed capacity, was made up of 22.4% hydropower and 77.6% thermal power (using natural gas as fuel) as shown in scenario 1 (Onagoruwa, 2011).

The ammonia losses due to housing and manure storage are assumed to be respectively 25% and 10%. These are based on the assumptions that i) roofed housing facility was used for keeping layers for a calendar year and also for temporarily keeping the spent layers for a day before slaughtering and ii) manure produced was temporarily stacked without turning (Government of Alberta, 2011).This study considers emissions from wastes due to storage during the laying period and one-day pre-slaughtering only. Emissions from solid wastes of frozen chicken processing (viscera, feathers, heads and feet) and inputs to waste treatment from processing of frozen chicken are not included in this study as the solid wastes produced from these processes are sold out.

The period from point-of-lay to spent layer lasts for some weeks i.e. bird starts laying at the age of 18-20 weeks depending on genetic and environmental factors such as light and nutrition. Laying continues thereafter for a period of one calendar year. After the onset of laying, peak production is attained within 6 weeks. At this stage, the rate of lay will be greater than 80-90%. This level of production will continue and gradually decline at about 48 weeks until it is uneconomical to keep the birds. The breed of birds used in this study was the near black breed of layers.

Roofed housing facility was used for keeping the layers for a year and also for temporary keeping of live spent layers for a day before slaughtering. The manure generated was temporarily stacked without turning. All activities from point-of-lay to spent layer were assumed to be carried out for 24 hours/day and 365 days a year. There is an exception for feed production and water pumping which are assumed to be for less than an hour per day.

All frozen chicken processing activities in this study were carried out for 7 hours/day, 6 days/week all year round. There was an exception for the blast cold rooms which were assumed to be in operation for 24 hours/day year-round. Live spent layers with an average live weight of 1.8 kg were slaughtered everyday for processing. Slaughtering was the only frozen chicken processing activity done manually and not accounted for in this study. It was assumed that each pack of chicken stayed for an average period of 24 hours in the blast cold rooms before it was taken to the gate (i.e. sold at gate) and that diesel was used in the transportation of birds and feed.

2.1. Life cycle inventory and assessment factors

An inventory of all the resources used and all the emissions released into the environment was done at the second stage of LCA. This covers all the activities within the system boundary from point-of-lay to frozen chicken production. Lighting the poultry houses, preparation of feed, transportation of birds and feed and carrying manure out of the housing facility were considered as work associated with animal management.

The emission factors for the consumption of purchased power account for the emissions from hydropower generation as well as the relatively large proportions of emissions from natural gas combustion at the thermal gas stations. Table 2 shows the environmental loads emission factors for purchased electricity. These emission factors do not include emissions associated with the construction of the reservoirs, extraction, production and transportation of the burnt fuel to produce electricity.

The primary energy conversion factors and GHG emission factors for diesel and natural gas were based on the Leonardo Academy's Cleaner and Greener Program (Leonardo Academy,

2009) which uses U.S. EPA's Emissions and Generation Resource Integrated Database's (eGRID) MS-Excel Aggregation workbook. This study assumed that hydropower generation, on the average, emits one-thirty-fifth of the GHGs that a natural gas generating station does (Hydro-Quebec, 2011). Table 3 shows the emission factors for diesel fuel based on data from National Pollutant Inventory (NPI, 2002) and University of Wisconsin Oshkosh (2008).

Table 2: Purchased electricity emission factors associated with frozen chicken production

Emissions	Natural gas factor		Hydropower factor	Equivalent purchased electricity factor
units	lbs per mmBtu	kg per kWh	kg per kWh	kg per kWh
CO_2	117.6	1.82E-01	1.35E-03	1.42E-01
CH_4	0.0225	3.48E-05	2.58E-07	2.71E-05
N_2O	0.0022	3.40E-06	2.52E-08	2.65E-06
SO_2	0.0006	9.29E-07	0	7.21E-07
NO_X	0.098	1.52E-04	0	1.18E-04

Scientific notation is used in the manuscript; e.g. 34.55E-06 represents 34.55 x 10^{-6} or 0.00003455.

Table 3: Diesel emission factors associated with frozen chicken production

Emissions	Diesel emission factor	Diesel emission factor
Units	kg per mmBtu	kg per litre
CO_2[a]	72.68	2.62
CH_4[a]	1.10E-02	3.97E-04
N_2O[a]	6.00E-04	2.16E-05
SO_2[b]	0.37	1.32E-02
NO_X[b]	5.50	1.99E-01

Scientific notation is used in the manuscript; e.g. 34.55E-06 represents 34.55 x 10^{-6} or 0.00003455.
a Source: NPI (2002). b Source: University of Wisconsin Oshkosh (2008).

All electricity emission factors were multiplied by the power ratings of equipment used in each processing activity while the loading rate and power factor of the diesel generators, together with the power ratings of equipment, were multiplied with the diesel emission factors in computing the emissions in the activities.

The global warming potential, an index for estimating the global warming contribution due to atmospheric emission of GHGs, was calculated using equation 1 and the CO_2–equivalent factors by Intergovernmental Panel on Climate Change (IPCC, 2007) for CO_2: 1, CH_4: 25 and N_2O: 298. These factors were set based on a time horizon of 100 years. The SO_2–equivalent factors for SO_2: 1, NO_X: 0.7 and NH_3: 1.88, derived from Azapagic (2003) and the PO_4–equivalent factors for NO_X: 0.13 and NH_3: 0.33, derived from Azapagic *et al.* (2004) were used in calculating the acidification and eutrophication potentials respectively with equations 2 and 3. For each scenario, the weight of each pollutant emitted was multiplied by its potential impact (GWP, AP or EP) equivalent factor. The total emission for each impact category was then calculated by adding the equivalents to arrive at the total CO_2, SO_2 and PO_4 equivalents for GWP, AP and EP respectively.

Mass of CO_2–equivalent = (Mass of gas in kg) x (global warming potential) (1)

Mass of SO_2–equivalent = (Mass of gas in kg) x (acidification potential) (2)

Mass of PO_4–equivalent = (Mass of gas in kg) x (eutrophication potential) (3)

3. Results and discussion

The effects of each process in the frozen chicken production on the environment based on the energy requirements of the equipment and their times of operation were examined. Total energy use and environmental impacts of producing 1.35 kg frozen chicken for four scenarios are presented from Table 4 to Table 7.

3.1. Impact assessment and scenario analysis

In this study, four scenarios were examined for reduction of environmental impacts as presented in Table 1. The first scenario was the use of 100% purchased electricity in all processing activities. The purchased electricity from the national grid was generated from hydropower and thermal power (using natural gas as fuel) in the ratio 22.4:77.6

The second scenario was the use of 100% electricity from diesel generators in all processing activities from point-of-lay to spent layer. The third and fourth scenarios were to use 50% each of both purchased electricity and diesel-generated electricity in all activities but with different ratios of hydropower to thermal power in the purchased electricity as shown in Table 1. The aim of the scenarios is to determine if there are significant changes in the environmental impact loads.

Table 4: Global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP) values for each activity in scenario 1

	Emission	Animal management	Water pumping	Scalding	Defeathering	Cutting	Packaging	Freezing	Feed production	Total	% of grand total
GWP	CO_2	5.92E-03	9.83E-05	2.97E-03	7.39E-04	7.39E-04	5.66E-04	4.56E-02	1.10E-02	6.77E-02	99.01
	CH_4	2.24E-05	4.70E-07	1.42E-05	3.53E-06	3.53E-06	2.71E-06	2.18E-04	5.27E-05	3.18E-04	0.46
	N_2O	1.46E-05	5.48E-07	1.66E-05	4.12E-06	4.12E-06	3.16E-06	2.54E-04	6.15E-05	3.59E-04	0.52
	Total	5.96E-03	9.93E-05	3.00E-03	7.46E-04	7.46E-04	5.72E-04	4.61E-02	1.11E-02	6.83E-02	100
	% of grand total	8.72	0.15	4.39	1.09	1.09	0.84	67.41	16.30	100	
AP	SO_2	2.99E-05	5.01E-10	1.51E-08	3.76E-09	3.76E-09	2.88E-09	2.32E-07	5.61E-08	3.02E-05	3.88E-03
	NO_X	3.14E-04	5.72E-08	1.73E-06	4.30E-07	4.30E-07	3.30E-07	2.65E-05	6.42E-06	3.50E-04	4.50E-02
	NH_3	7.78E-01	0	0	0	0	0	0	0	7.78E-01	99.95
	Total	7.79E-01	5.77E-08	1.75E-06	4.34E-07	4.34E-07	3.32E-07	2.68E-05	6.47E-06	7.79E-01	100
	% of grand total	99.99	7.41E-06	2.24E-04	5.57E-05	5.57E-05	4.27E-05	3.44E-02	8.32E-04	100	
EP	NO_X	5.84E-05	1.06E-08	3.21E-07	7.99E-08	7.99E-08	6.12E-08	4.93E-06	1.19E-06	6.51E-05	4.76E-02
	NH_3	1.37E-01	0	0	0	0	0	0	0	1.37E-01	99.95
	Total	1.37E-01	1.06E-08	3.21E-07	7.99E-08	7.99E-08	6.12E-08	4.93E-06	1.19E-06	1.37E-01	100
	% of grand total	99.99	7.78E-06	2.35E-04	5.84E-05	5.84E-05	4.48E-05	3.61E-03	8.72E-04	100	

Units: GWP – kg CO_2 equivalent; AP – kg SO_2 equivalent; EP – kg PO_4 equivalent. All values are for a functional unit.
Scientific notation is used in the manuscript; e.g. 34.55E-06 represents 34.55 x 10^{-6} or 0.00003455.

Table 5: Global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP) values for each activity in scenario 2

	Emission	Animal management	Water pumping	Scalding	Defeathering	Cutting	Packaging	Freezing	Feed production	Total	% of grand total
GWP	CO_2	5.92E-03	1.72E-04	5.21E-03	1.29E-03	1.29E-03	9.92E-04	7.99E-02	1.93E-02	1.14E-01	99.38
	CH_4	2.24E-05	6.52E-07	1.97E-05	4.90E-06	4.90E-06	3.75E-06	3.02E-04	7.31E-05	4.32E-04	0.38
	N_2O	1.46E-05	4.24E-07	1.28E-05	3.18E-06	3.18E-06	2.44E-06	1.97E-04	4.75E-05	2.81E-04	0.24
	Total	5.96E-03	1.73E-04	5.24E-03	1.30E-03	1.30E-03	9.98E-04	8.04E-02	1.94E-02	1.15E-01	
	% of grand total	5.19	0.15	4.56	1.13	1.13	0.87	70.02	16.93	100	
AP	SO_2	2.99E-05	8.68E-07	2.63E-05	6.52E-06	6.52E-06	5.00E-06	4.03E-04	9.74E-05	5.75E-04	0.07
	NO_X	3.14E-04	9.14E-06	2.76E-04	6.87E-05	6.87E-05	5.26E-05	4.24E-03	1.03E-03	6.06E-03	0.77
	NH_3	7.78E-01	0	0	0	0	0	0	0	7.78E-01	99.16
	Total	7.79E-01	1.00E-05	3.03E-04	7.52E-05	7.52E-05	5.76E-05	4.64E-03	1.12E-03	7.85E-01	
	% of grand total	99.20	1.28E-03	0.04	9.58E-03	9.58E-03	7.34E-03	0.59	0.14	100	
EP	NO_X	1.48E-04	4.31E-06	1.30E-04	3.24E-05	3.24E-05	2.48E-05	2.00E-03	4.83E-04	2.85E-03	2.05
	NH_3	1.37E-01	0	0	0	0	0	0	0	1.37E-01	97.95
	Total	1.37E-01	4.31E-06	1.30E-04	3.24E-05	3.24E-05	2.48E-05	2.00E-03	4.83E-04	1.40E-01	
	% of grand total	98.06	3.09E-03	0.09	0.02	0.02	1.78E-02	1.43	0.35	100	

Units: GWP – kg CO_2 equivalent; AP – kg SO_2 equivalent; EP – kg PO_4 equivalent. All values are for a functional unit.
Scientific notation is used in the manuscript; e.g. 34.55E-06 represents 34.55 x 10^{-6} or 0.00003455.

Table 6: Global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP) values for each activity in scenario 3

	Emission	Animal management	Water pumping	Scalding	Defeathering	Cutting	Packaging	Freezing	Feed production	Total	% of grand total
GWP	CO_2	5.92E-03	1.35E-04	4.09E-03	1.02E-03	1.02E-03	7.79E-04	6.27E-02	1.52E-02	9.09E-02	99.24
	CH_4	2.24E-05	5.61E-07	1.70E-05	4.22E-06	4.22E-06	3.23E-06	2.60E-04	6.29E-05	3.75E-04	0.41
	N_2O	1.46E-05	4.86E-07	1.47E-05	3.65E-06	3.65E-06	2.80E-06	2.25E-04	5.45E-05	3.20E-04	0.35
	Total	5.96E-03	1.36E-04	4.12E-03	1.02E-03	1.02E-03	7.85E-04	6.32E-02	1.53E-02	9.16E-02	
	% of grand total	6.51	0.15	4.50	1.12	1.12	0.86	69.05	16.70	100	
AP	SO_2	2.99E-05	4.34E-07	1.31E-05	3.26E-06	3.26E-06	2.50E-06	2.01E-04	4.87E-05	3.03E-04	0.04
	NO_X	3.14E-04	4.60E-06	1.39E-04	3.46E-05	3.46E-05	2.65E-05	2.13E-03	5.16E-04	3.20E-03	0.41
	NH_3	7.78E-01	0	0	0	0	0	0	0	7.78E-01	99.55
	Total	7.79E-01	5.03E-06	1.52E-04	3.78E-05	3.78E-05	2.90E-05	2.33E-03	5.65E-04	7.82E-01	
	% of grand total	99.60	6.44E-04	0.019466692	4.84E-03	4.84E-03	3.71E-03	0.30	7.22E-02	100	
EP	NO_X	5.84E-05	8.54E-07	2.58E-05	6.42E-06	6.42E-06	4.92E-06	3.96E-04	9.58E-05	5.95E-04	0.43
	NH_3	1.37E-01	0	0	0	0	0	0	0	1.37E-01	99.57
	Total	1.37E-01	8.54E-07	2.58E-05	6.42E-06	6.42E-06	4.92E-06	3.96E-04	9.58E-05	1.37E-01	
	% of grand total	99.61	6.23E-04	0.018821363	4.68E-03	4.68E-03	3.59E-03	0.29	6.98E-02	100	

Units: GWP – kg CO_2 equivalent; AP – kg SO_2 equivalent; EP – kg PO_4 equivalent. All values are for a functional unit.
Scientific notation is used in the manuscript; e.g. 34.55E-06 represents 34.55 x 10^{-6} or 0.00003455.

Table 7: Global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP) values for each activity in scenario 4

	Emission	Animal management	Water pumping	Scalding	Defeathering	Cutting	Packaging	Freezing	Feed production	Total	% of grand total
GWP	CO_2	5.92E-03	1.18E-04	3.57E-03	8.87E-04	8.87E-04	6.79E-04	5.47E-02	1.32E-02	8.00E-02	99.28
	CH_4	2.24E-05	4.78E-07	1.45E-05	3.59E-06	3.59E-06	2.75E-06	2.22E-04	5.36E-05	3.23E-04	0.40
	N_2O	1.46E-05	3.89E-07	1.18E-05	2.93E-06	2.93E-06	2.24E-06	1.81E-04	4.37E-05	2.59E-04	0.32
	Total	5.96E-03	1.19E-04	3.59E-03	8.93E-04	8.93E-04	6.84E-04	5.51E-02	1.33E-02	8.06E-02	
	% of grand total	7.40	0.15	4.46	1.11	1.11	0.85	68.39	16.54	100	
AP	SO_2	2.99E-05	4.34E-07	1.31E-05	3.26E-06	3.26E-06	2.50E-06	2.01E-04	4.87E-05	3.03E-04	0.04
	NO_X	3.14E-04	4.59E-06	1.39E-04	3.45E-05	3.45E-05	2.64E-05	2.13E-03	5.15E-04	3.20E-03	0.41
	NH_3	7.78E-01	0	0	0	0	0	0	0	7.78E-01	99.55
	Total	7.79E-01	5.02E-06	1.52E-04	3.77E-05	3.77E-05	2.89E-05	2.33E-03	5.63E-04	7.82E-01	
	% of grand total	99.60	6.43E-04	1.94E-02	4.83E-03	4.83E-03	3.70E-03	0.30	7.21E-02	100	
EP	NO_X	5.84E-05	8.52E-07	2.58E-05	6.40E-06	6.40E-06	4.91E-06	3.95E-04	9.56E-05	5.94E-04	0.43
	NH_3	1.37E-01	0	0	0	0	0	0	0	1.37E-01	99.57
	Total	1.37E-01	8.52E-07	2.58E-05	6.40E-06	6.40E-06	4.91E-06	3.95E-04	9.56E-05	1.37E-01	
	% of grand total	99.61	6.21E-04	1.88E-02	4.67E-03	4.67E-03	3.58E-03	0.29	6.97E-02	100	

Units: GWP – kg CO_2 equivalent; AP – kg SO_2 equivalent; EP – kg PO_4 equivalent. All values are for a functional unit.
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3.1.1. Global Warming Potential

The contributions of each processing activity to global warming are shown in Tables 4, 5, 6 and 7. The grand total global warming potential value for Scenario 2 is predominantly higher than the values for other three scenarios (Table 8). The reason behind this is that there are more emissions from the combustion of diesel than for using either purchased power solely or combining it with diesel in any proportion. There are comparatively smaller emission factors for purchased electricity, which is a national power mix of hydroelectricity and thermal electricity. Simply changing the ratio of thermal power to hydropower in scenario 3 to that in scenario 4 reduces grand total global warming by 12% (Table 8) due to relatively smaller emission factors for hydropower. Scenario 1 has the least global warming impact of 0.00683 kg CO_2 equivalent/FU, which is 40.5% smaller that that of scenario 2 (100% diesel fuel).

For all scenarios, the tables show that the major contributor to global warming is freezing which accounts for about 70% of the total contribution, mainly due to CO_2 emission. This is as a result of the 24 hour/day operation of the blast freezers. Feed production accounted for about 17% of the total contribution in all scenarios. Water pumping has the lowest impact (0.15%), followed by packaging (about 0.84%).

3.1.2. Acidification Potential

The contributions of each processing activity to acidification are shown in Tables 4, 5, 6 and 7. This impact category depends mostly on the NH_3 emissions from animal management and is due to the similar housing facility and stacking of waste from poultry. NH_3 emissions from all scenarios accounts for nearly 100% of the total contribution. Similar to the GWP, the AP value for scenario 2 is higher than the values for other scenarios, though very slightly. This is as a result of higher amounts of NO_X and SO_X emitted by diesel generators.

Acidification potential (AP) throughout the life cycle of the four scenarios ranges from 0.7786 kg SO_2 equivalent for scenario 1 to 0.7849 kg SO_2 equivalent for scenario 2, the value for scenarios 3 and 4 falling slightly below the latter (Table 8).

The acidification potential associated with frozen chicken production is nearly similar in all scenarios and as a result, changing from scenario 2 (100% diesel) to scenario 1 (100% purchased power) does not lead to any significant improvements.

3.1.3. Eutrophication Potential

The total contributions of each processing activity to acidification are shown in Tables 4, 5, 6 and 7. Eutrophication potential (EP) throughout the life cycle of the four scenarios ranges from 0.1367 kg PO_4 equivalent for scenario 1 to 0.1395 kg PO_4 equivalent for scenario 2. Scenarios 3 and 4 have the same EP value of 0.1372 kg PO_4 equivalent. While all the scenarios have similar NH_3 emissions (0.137 kg PO_4-eq) due to waste from similar housing facility, the higher emission of NO_X in Scenario 2 drives its overall EP value slightly higher.

In all scenarios, animal management accounts for almost all of the EP contribution. Compared to the air-related impact categories, the EP values for all scenarios are not significantly affected by the national power mix (Table 8) and the values for all the scenarios are driven by the NH_3 emissions from animal management.

Table 8: Impact assessment summary

Scenario	Global Warming Potential (kg CO_2 equivalent/FU)	Acidification Potential (kg SO_2 equivalent/FU)	Eutrophication Potential (kg PO_4 equivalent/FU)
Scenario 1	0.683E-01	7.786E-01	1.367E-01
Scenario 2	1.148E-01	7.849E-01	1.395E-01
Scenario 3	0.916E-01	7.817E-01	1.372E-01
Scenario 4	0.806E-01	7.817E-01	1.372E-01

Scientific notation is used in the manuscript; e.g. 34.55E-06 represents 34.55 x 10^{-6} or 0.00003455.

3.1.4. Energy Use

Energy use (EU) throughout the life cycle of the four scenarios is the same with a value of 1.656 MJ/FU (Figure 2). This is because the same processing equipment were used in all scenarios. Freezing and feed production both account for about 87% of the EU in all scenarios with values of 1.16 MJ/FU and 0.28 MJ/FU respectively. The relatively high value for freezing is due to longer operating hours and power ratings of the blast freezers. Scalding, which involves the use of boilers, and animal management both contribute only about 10% of the total EU in each scenario. The EU associated with cutting is very similar to that associated with packaging.

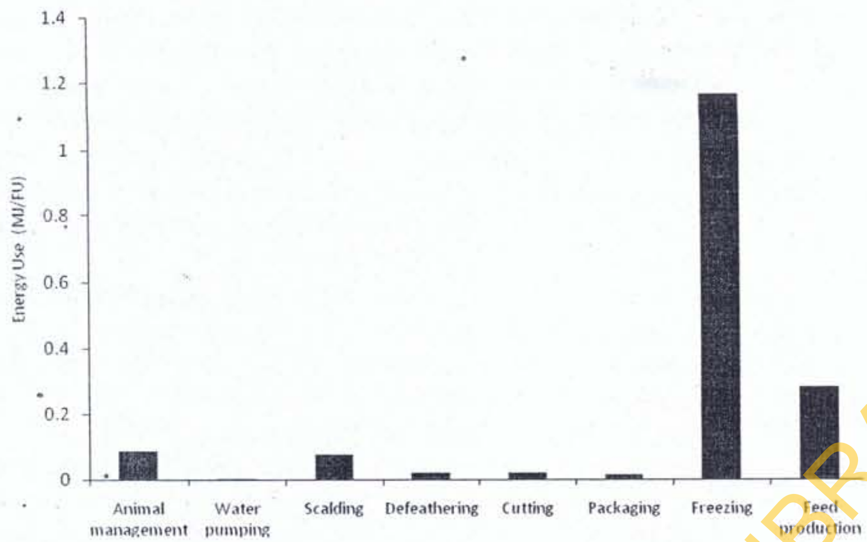

Figure 2: The contribution of each processing activity to Energy Use for the production of a functional unit of frozen chicken.

Improvement analysis

As mentioned, the electricity production from diesel generators has been responsible for a considerable portion of total GHG emissions. There are numerous technological solutions which offer substantial CO_2 reduction potentials, including renewable energies, higher efficiency power generation, fossil-fuel use with CO_2 capture and storage, fusion energy, nuclear fission, hydrogen, fuel cells, biofuels, and efficient energy end use. No single technology can meet this challenge by itself. Different regions and countries will need different combinations of technologies to best serve their needs and best exploit their indigenous resources (IEA, 2003). Nigeria's power systems presently depend on hydropower and thermal power majorly, but power systems of the future must rely on a mix of different advanced, clean, efficient technologies for energy supply and use. Fossil and non-fossil forms of energy will be needed in the likely future to meet national energy demands.

With the present state of power generation in Nigeria, coupled with its erratic supply to consumers, most agricultural establishments rely on diesel generators either as back-up or their main sources of electricity. Hence in terms of energy use, reliance on hydropower plants instead of the thermal plants that are run on natural gas impacted minimally on the environmental load. Hence, Power Holding Company of Nigeria (PHCN) advocacy for shift from hydro to thermal plants should be considered with caution in terms global environmental impacts.

Thus, to reduce environmental impacts, various emission control technologies including high efficiency diesel particulate filters, flow through filters, diesel extraction catalysts, selective catalysts, reduction, NO_x absorbers etc., could be used. These technologies could reduce emissions by about 80-90%.

The major contributor to the waste load in this study was animal management which included the housing facility for raising layers and for temporary keeping of spent layers. NH_3 reduction can be done using acidified biochar (Doydora *et al*, 2011). This reduces NH_3 losses by about 58-63%.

The efficiency of all production processes can be improved by technology development and good housekeeping practices. For example, stunning live birds before killing them reduces the overall blood loss from splashes. Full-scale poultry slaughterhouse wastewater treatment could be used to remove organic matter (Del Nery *et al.,* 2007) and fully automated slaughtering machine could improve the efficiency frozen chicken production.

Energy efficient equipment (e.g. fluorescent lamps) could be used instead of incandescent bulbs, transportation vehicles could be well maintained, and efficient water heaters, freezers and conditioners could be used to minimize power and fuel consumption. Economical use of water could be ensured by avoiding overflows and leaks.

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